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ECOSYSTEMS

SPECIAL FEATURE

Surrogates for Resilience of Social–Ecological Systems

Stephen R. Carpenter,[1]* Frances Westley,[2] and Monica G. Turner[3]

[1]*Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706, USA;* [2]*Institute of Environmental Studies, University of Wisconsin, Madison, Wisconsin 53706, USA;* [3]*Department of Zoology, University of Wisconsin, Madison, Wisconsin 53706, USA*

INTRODUCTION

From its roots in ecology, resilience (Holling 1973) has more recently been applied to social–ecological systems, or SES. Theories of changing resilience explicitly address the persistence or breakdown of diverse states of complex systems (Gunderson and Holling 2002). These ideas have attracted interest from interdisciplinary research groups interested in change, conservation or restoration of SES (Berkes and others 2003; Scheffer and others 2003). From a practical standpoint, resilience theory provides a conceptual foundation for sustainable development (Folke and others 2002). The transition from theory to practice, however, requires assessment or estimation of resilience (Carpenter and others 2001). So far, there is little experience with estimating resilience of SES, and little understanding of the sensitivity of resilience measures to changes in SES. This shortage of practical field experience is a barrier to building understanding through empirical study of resilience in SES.

Direct measurement of resilience is difficult because it requires measuring the thresholds or boundaries that separate alternate domains of dynamics for SES. The only sure way to detect a threshold in a complex system is to cross it (Carpenter 2003). Yet threshold-crossings do not occur very often. In the natural sciences, much understanding of thresholds has come from deliberate manipulations of ecosystems, or before/after studies of large disturbances (Turner and Dale 1998; Groffman and others 2005). In interdisciplinary science, it may be impossible, unethical or both to induce a threshold-crossing in an SES. It may be possible to assess SES thresholds retrospectively, through historical analysis of case studies. But, especially in applications of resilience to pressing environmental problems, we may be interested in present-day resilience or future resilience of an SES. Indirect inferences are unavoidable in such circumstances.

Resilience measures differ from traditional ecological indicators (for example, National Research Council 2000) in several respects. For this reason, we use the word ‘‘surrogates’’ instead of ‘‘indicators’’. By referring to surrogates, we acknowledge that important aspects of resilience in SES may not be directly observable, but must be inferred indirectly. We also acknowledge that resilience and its relationship to the surrogates may change over time. Resilience surrogates should correspond in a specified way to theoretical aspects of resilience. According to resilience theory, the aspects of a system that confer resilience depend on context (Holling 2001). These change: over time, with spatial configuration, among the diverse ecosystems that may comprise a regional SES, and among groups of people participating in the SES. Consequently, the relationship between resilience and any particular surrogate may be dynamic, complex, and multidimensional. In general, practitioners will need a suite of resilience surrogates that jointly represent the key features of resilience, in context, for the particular SES at hand.

In this early stage of research, there are only a few guidelines for resilience surrogates. The user

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**Corresponding author; e-mail:* srcarpen@wisc.edu

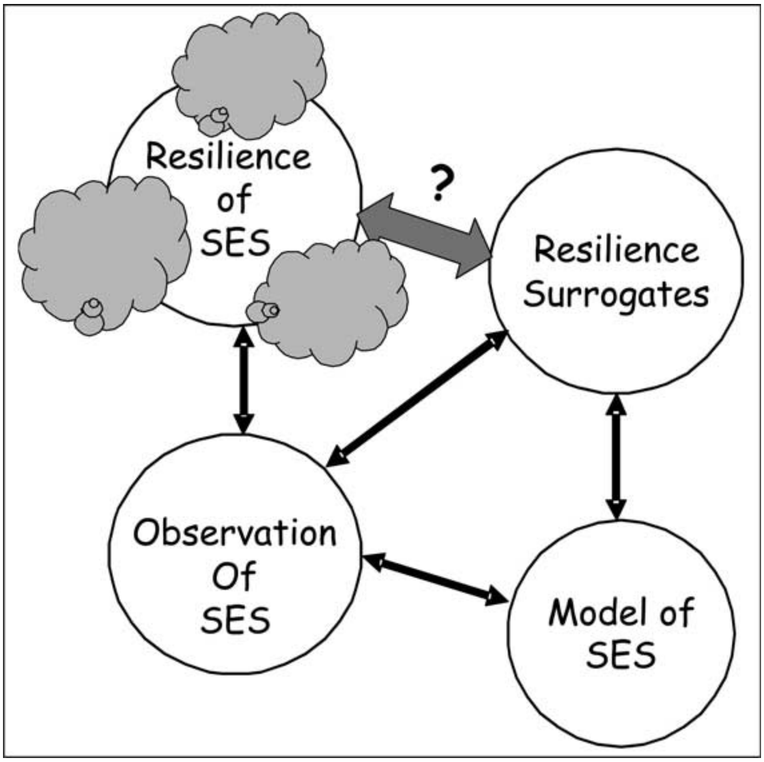

Figure 1. In most cases, resilience of an SES is shrouded by barriers to observation, and can be observed only partially or indirectly. Surrogates are inferred from observations, often with the aid of models. The relationships among observations, surrogates and models should be explicit and transparent. However, the relationship of the surrogate to resilience of the SES is usually uncertain.

should be able to state the relationship of the surrogate to a particular theoretical notion of resilience. A surrogate should be consistent and repeatable, in the sense that independent observers given the same information would assess the surrogate in the same way. Resilience surrogates will often be context-dependent, and the nature of this context-dependency should be spelled out. It should be possible to assess the surrogate for a range of SESs, or in an SES over time. The surrogate should be part of a set of complementary surrogates that address multiple aspects of resilience.

The goal of this Special Feature is to explore resilience surrogates from the practical perspective of scientists who seek connections between theory and observable aspects of resilience in SES.

Conceptual Basis for Surrogates

Although the resilience of an SES will not often be observable directly, many features of the SES can be observed (Figure 1). Surrogates for resilience depend on the observations as well as models of the SES. A model is a device which makes an abstraction concrete, so that the abstraction can be manipulated to understand it and compare it with observations and other models. In this Special Feature, the abstraction of interest is the theoretical notion of resilience. Examples of models include the diverse individual models held by people in the SES; soft models such as art, stories or scenarios; technical diagrams; maps; heuristic mathematical models, simplified for rapid understanding; and detailed integrated system models.

The core question is: What surrogates for resilience are consistent with the resilience of the SES? Because the resilience of the SES is not directly observable, this question cannot directly be answered. However, some related questions can be addressed:

- Are the surrogates consistent with resilience in modeling exercises?
- Are the surrogates consistent with long-term observations of the SES?
- Are the surrogates consistent in comparisons across SESs?
- In cases where SES have changed substantially, thereby revealing thresholds, were the surrogates consistent with the observed changes?

Pathways for Inventing Surrogates

There is no single ‘‘correct mechanism’’ for developing resilience surrogates. Researchers appear to have used four general approaches.

- Stakeholder assessments: Aspects of SES resilience or vulnerability are identified through workshops aimed at building a common understanding of change in the SES.

- Model explorations: Models of the SES (such as scenarios or computer simulation models) are used to explore the potential thresholds for change, and identify measurable aspects of the SES that have systematic relationships to the modeled thresholds.
- Historical profiling: History of the SES is assessed to classify more-or-less distinct dynamic regimes, and analyze events during the transitions. At these crucial times when resilience mattered, what changed and how?
- Case study comparison: SESs that have many similarities, but appear to be changing in different ways, are examined to assess observable properties that may be related to resilience. What is different among systems that appear to have quite different resilience?

These approaches have complementary strengths and weaknesses. For example, the case-study approach suffers from the same difficulties as space-for-time substitution in ecology (Pickett 1989). Did the inter-SES differences cause differences in resilience, or vice versa? This problem could perhaps be overcome by comparing histories of the SES, which would reveal thresholds of change and their characteristics. In any particular project, it makes sense to use as many different approaches as possible to identify resilience surrogates. Surrogates that appear to be useful and consistent from all four approaches are likely to be more robust.

Preview of the Special Feature

The Special Feature includes papers that address surrogates primarily from a theoretical perspective as well as papers that take practical field problems as a starting point. All papers focus on integrated social–ecological systems, not just social or ecological components of systems. The international group of contributing authors includes both social and natural scientists. Field examples are drawn from several regions of the world.

Bennett, Cumming and Peterson examine the use of two types of models, scenarios and simulation models, to explore resilience in SES. The main point is that destabilizing or stabilizing processes in the system, exposed through modeling or scenario exploration, are a good place to look for surrogates of resilience. Allen, Gunderson, and Johnson provide a different theoretical perspective on surrogates. They focus on the search for discontinuities in data sets from complex systems. Berkes and Seixas investigate the role of memory and adaptive learning in SES. Their study suggests that surrogates of resilience lie in features of societies' environmental monitoring capacities, as well as in societies' ability to detect and act appropriately upon signals of ecosystem change. Cumming, Barnes, Perz and colleagues close out the Special Feature by illustrating an empirical-based approach for comparative resilience assessment, illustrated using contrasting regions in the Americas.

Progress on surrogates is essential for bridging from theories of resilience to field-based interdisciplinary research. We believe that this Special Feature provides a glimpse of the future in this exciting, young and still-developing research area.

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